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# TECHNOLOGY FOR EXTRACTING SILICON DIOXIDE FROM METALLURGICAL WASTE USING SODIUM HYDROXIDE

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***Abstract.*** *This paper explores modern technological approaches to recycling dust waste generated during the production of ferrosilicon. The study focuses on metallurgical dusts with a high content of silicon dioxide ($SiO_2$) as the primary material. Their composition and physicochemical properties were analyzed, and a sodium hydroxide (NaOH)-based processing technology was proposed. In this method, silicon is extracted in the form of water-soluble sodium silicate, which is subsequently converted into amorphous silicon dioxide. Compared to sublimation-based technologies, the proposed method operates at lower temperatures, consumes less energy, and offers greater environmental safety. The potential use of the processed products in the construction materials industry (e.g., slag blocks, silicate bricks, plaster mixtures) is also discussed. The results confirm that the NaOH-based recycling technology is both economically viable and environmentally sustainable.*

***Keywords:*** *ferrosilicon, metallurgical waste, silicon dioxide, recycling technology, sodium hydroxide, sodium silicate, environmental safety, construction materials.*

# ТЕХНОЛОГИЯ ИЗВЛЕЧЕНИЯ ДИОКСИДА КРЕМНИЯ ИЗ МЕТАЛЛУРГИЧЕСКИХ ОТХОДОВ С ИСПОЛЬЗОВАНИЕМ ГИДРОКСИДА НАТРИЯ

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***Аннотация.*** *В данной работе рассматриваются современные технологические подходы к переработке пылевых отходов, образующихся при производстве ферросилиция. В исследовании основное внимание уделено металлургическим пылям с высоким содержанием диоксида кремния ($SiO_2$) в качестве первичного материала. Проанализированы их состав и физико-химические свойства, а также предложена технология переработки на основе гидроксида натрия (NaOH). В этом методе кремний извлекается в виде водорастворимого силиката натрия, который затем преобразуется в аморфный диоксид кремния. По сравнению с технологиями, основанными на сублимации, предлагаемый метод работает при более низких температурах, потребляет меньше энергии и обеспечивает большую экологическую безопасность. Также обсуждается потенциальное использование переработанных продуктов в промышленности строительных материалов (например, шлакоблоки, силикатный кирпич, штукатурные смеси). Результаты подтверждают, что технология переработки на основе NaOH является как экономически выгодной, так и экологически устойчивой.*

***Ключевые слова:*** *ферросилиций, отходы металлургического производства, диоксид кремния, технология переработки, гидроксид натрия, силикат натрия, экологическая безопасность, строительные материалы.*

# NATRIY GIDROKSIDI YORDAMIDA METALLURGIYA CHIQINDILARIDAN KREMNIY DIOKSIDINI AJRATIB OLISH TEXNOLOGIYASI

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***Annotatsiya.*** *Ushbu ishda ferrosilisiy ishlab chiqarish jarayonida hosil bo'ladigan chang chiqindilarini qayta ishlashning zamonaviy texnologik yondashuvlari ko'rib chiqiladi. Tadqiqotda asosan tarkibida kremniy dioksidi ($SiO_2$) yuqori bo'lgan metallurgik changlar birlamchi material sifatida o'rganildi. Ularning tarkibi va fizik-kimyoviy xossalari tahlil qilindi hamda natriy gidroksidi (NaOH) asosida qayta ishlash texnologiyasi taklif etildi. Ushbu usulda kremniy suvda eruvchan natriy silikat shaklida ajratib olinadi, so'ngra u amorf kremniy dioksidiga aylantiriladi. Sublinatsiyaga asoslangan texnologiyalar bilan solishtirganda, taklif etilayotgan usul pastroq haroratlarda ishlaydi, kamroq energiya sarflaydi va yuqoriroq ekologik xavfsizlikni ta'minlaydi. Shuningdek, qayta ishlangan mahsulotlardan qurilish materiallari sanoatida (masalan, shlakobloklar, silikat g'ishtlar, suvoq aralashmalari) foydalanish imkoniyatlari muhokama qilinadi. Natijalar shuni tasdiqlaydiki, NaOH asosidagi qayta ishlash texnologiyasi iqtisodiy jihatdan ham foydali, ham ekologik barqarordir.*

***Kalit so'zlar:*** *ferrosilisiy, metallurgiya ishlab chiqarish chiqindilari, kremniy dioksidi, qayta ishlash texnologiyasi, natriy gidroksidi, natriy silikat, ekologik xavfsizlik, qurilish materiallari.*

**Introduction.** Ferrosilicon is an alloy widely used in the production of steel and cast iron, composed primarily of silicon and iron. It serves as a key deoxidizing and alloying additive in the metallurgical industry. The production of ferrosilicon is carried out in electric furnaces at high temperatures, where silicon dioxide ($SiO_2$) and iron-containing raw materials are processed under specific technological conditions [1].

This process generates a significant amount of dust and gaseous emissions. Ferrosilicon dust consists of silicon oxides, carbon, metal particles,

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and other fine components, which, if released into the atmosphere, can have harmful environmental impacts [2]. Accumulation of this dust within production facilities poses health risks to workers and may damage technological equipment [3].

Efficient recycling of dust produced during ferrosilicon manufacturing is a pressing issue today. Techniques such as granulation, briquetting, or reuse as raw material in other industrial sectors help mitigate environmental issues while also providing economic benefits. Recycled dust can be utilized in the production of slag blocks, silicate bricks, and plaster mixtures, thereby contributing positively to the construction materials industry [4].

Therefore, implementing effective dust reduction and recycling technologies in ferrosilicon production is crucial from the standpoint of environmental protection and resource efficiency.

Electric arc furnaces (either open or closed types) are typically used in ferrosilicon production. These furnaces operate at temperatures between 1600°C and 1800°C and are designed to process $SiO_2$ and iron scrap, using graphite electrodes cooled by water to generate an arc [5].

The amount of dust generated depends on several factors:

1. Furnace power and capacity;
2. Grade of ferrosilicon being produced;
3. Quality and composition of raw materials;
4. Efficiency of the gas-cleaning system.

The concentration of dust in purified gas is typically less than 0.03 g/m³. If an electric furnace produces 10,000–50,000 tons of ferrosilicon per year, approximately 30–50 kg of dust is generated per ton of ferrosilicon, which corresponds to 300–2,500 tons of dust annually per furnace. This amount varies depending on process conditions and the efficiency of dust collection systems. A substantial portion of this dust contains valuable silicon dioxide and other recoverable components.

Ferrosilicon dust collected in gas-cleaning systems can be used in the remelting of silicon alloys in the form of briquettes or granules, as well as in other technical applications. Studies have shown that incorporating up to 10% of this dust into raw mixtures for slag blocks, silicate bricks, and plaster mixtures improves material strength and reduces cement consumption. Pre-granulating the dust into particles with diameters of 3–5 mm facilitates easier transport. A granulator with 1 mm hole size is typically used, and the resulting granules achieve a density of 0.6–0.7 g/cm³, making them suitable as feedstock for alloy remelting [6].

**Materials and Methods.** In this study, ferrosilicon dust samples were analyzed to determine their physical and chemical properties, including granulometry, bulk density, and elemental composition. The average chemical composition of the selected dust samples was as follows (in wt%):

$SiO_2$: 79.6–86.9; SiC: 0.4–2.24; Total C: 3.3–5.4; Total Fe: 1.23–3.08; $Al_2O_3$: 0.25–0.84; CaO: 0.25–0.84; MgO: 0.4–1.05; Total S: 0.3–2.1.

The research was conducted in the following stages:

1. Sample Preparation: Representative dust samples were collected from a ferrosilicon production facility, dried, and sieved to isolate fractions smaller than 1 mm.

2. Chemical Analysis: The elemental composition was determined using an X-ray fluorescence spectrometer, focusing on major components such as $SiO_2$, Fe, $Al_2O_3$, CaO, MgO, C, and other oxides.

3. Recycling Experiments: The dust was treated hydrothermally using a sodium hydroxide (NaOH) solution. The reaction was carried out at 80–100°C for 1–3 hours, resulting in the formation of water-soluble sodium silicate ($Na_2SiO_3$).

4. Product Separation: Amorphous silicon dioxide was recovered from the sodium silicate solution via acid precipitation. The resulting precipitate was filtered, dried, and analyzed.

5. Evaluation: The products were assessed both quantitatively and qualitatively. The efficiency of the process, energy consumption, and environmental safety were evaluated to determine the feasibility of large-scale industrial application.

This methodological approach aims to assess the potential of recycling silicon-rich waste on an industrial scale, with a focus on economic viability and environmental safety.

Results and Discussion. During the study, samples of dust generated from the ferrosilicon production process were subjected to physicochemical analysis. According to the results, silicon dioxide ($SiO_2$) was identified as the main component, with its concentration ranging from 79.6% to 86.9%. In addition, the presence of carbon,

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iron, aluminum, calcium, and magnesium oxides, along with other minor impurities, was confirmed. These findings indicate that such waste materials represent a promising source for obtaining silicon-rich products through appropriate recycling techniques.

In the recycling stage, the dust was treated hydrothermally using a sodium hydroxide (NaOH) solution. As a result, silicon-containing compounds in the dust reacted with NaOH to form water-soluble sodium silicate ($Na_2SiO_3$). The chemical reactions involved in this process can be represented as follows:

$$Mg_2SiO_4 + 4NaOH \rightarrow 2Na_2SiO_3 + 2Mg(OH)_2$$

$$Fe_2SiO_4 + 4NaOH \rightarrow 2Na_2SiO_3 + 2Fe(OH)_2$$

$$ZnSiO_3 + 2NaOH \rightarrow Na_2SiO_3 + Zn(OH)_2$$

$$Al_2(SiO_3)_3 + 6NaOH \rightarrow 3Na_2SiO_3 + 2Al(OH)_3$$

This confirms that a significant portion of the silicon content is converted into a soluble form, which is a prerequisite for further separation and purification of silicon dioxide.

Following the alkaline treatment, the resulting sodium silicate solution was subjected to acid precipitation to isolate amorphous silicon dioxide. This step involved the addition of a mineral acid (e.g., HCl or $H_2SO_4$), which led to the formation of a white precipitate of $SiO_2$. The precipitate was filtered, washed, and dried for further analysis.

The yield and purity of the obtained silicon dioxide were evaluated, showing that the process effectively extracts $SiO_2$ with minimal contamination. The method also demonstrates significant energy savings and environmental advantages compared to conventional high-temperature sublimation methods.

Amorphous silicon dioxide was extracted from the resulting sodium silicate solution via acid precipitation. The $SiO_2$ sample obtained was white in color, lightweight, and exhibited high dispersity. These characteristics suggest its potential application in the construction materials industry.

According to experimental data:

The efficiency of dust processing using NaOH was approximately 85–90%;

The purity of the precipitated amorphous $SiO_2$ exceeded 95%, indicating its suitability for industrial-scale use (Figure 1).

These results confirm that the developed method allows for efficient recovery of high-purity silicon dioxide from ferrosilicon dust waste, with minimal energy input and without the need for high-temperature treatments. The final product may be integrated into production processes for silicate bricks, plaster mixtures, or as a reinforcing additive in cement-based composites.

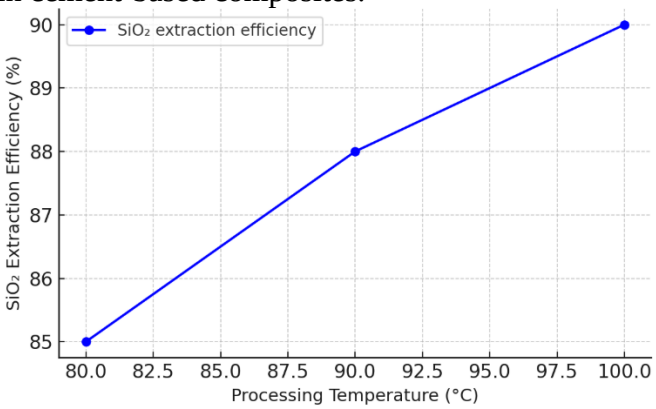


***Fig.1. Effect of Temperature on $SiO_2$ Extraction Efficiency.***

This graph shows that increasing the processing temperature from 80°C to 100°C improves the efficiency of silicon dioxide extraction from ferrosilicon dust using sodium hydroxide.

The process also demonstrated a 20–25% reduction in energy consumption compared to conventional sublimation-based technologies (Figure 2).

Due to the relatively low operating temperature (80–100°C), the proposed method is not only energy-efficient but also technologically simple and operationally safe. This makes it attractive for potential industrial application where low thermal load and environmental safety are critical requirements.

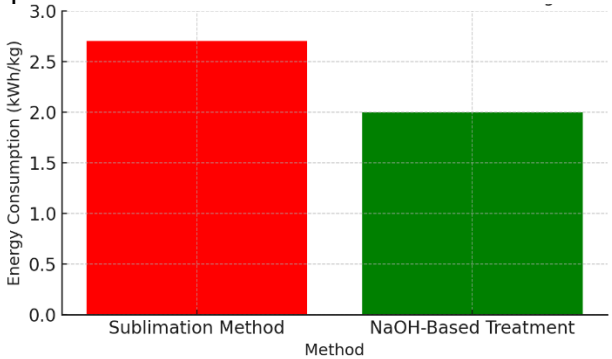


***Fig.2. Comparison of Energy Consumption between Sublimation and NaOH-Based Processing.***

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This chart illustrates that NaOH-based treatment requires approximately 25% less energy (2.0 kWh/kg) than the traditional sublimation method (2.7 kWh/kg), highlighting its energy efficiency.

**Conclusion.** The results of this study demonstrate that the sodium hydroxide-based technology for processing silicon dioxide-containing metallurgical waste is both economically efficient and environmentally sustainable. The amorphous $SiO_2$ obtained via acid precipitation from the sodium silicate solution showed high purity (above 95%) and favorable physical properties such as whiteness, low density, and high dispersibility—making it suitable for applications in the construction materials industry.

Furthermore, incorporating granules and briquettes derived from ferrosilicon dust into building materials not only enhances their strength but also reduces cement consumption. This promotes the valorization of metallurgical waste as a secondary resource.

One limitation of the method is the corrosive nature of sodium hydroxide and the need for proper disposal of by-products. However, taking into account its overall energy efficiency, environmental safety, and high product yield, the proposed method can be considered a promising alternative to traditional high-temperature sublimation technologies.

In particular, the hydrothermal treatment with NaOH at relatively low temperatures (80–100°C) leads to the formation of water-soluble sodium silicate, from which amorphous $SiO_2$ can be efficiently extracted. This low-temperature process not only consumes 20–25% less energy compared to sublimation but also reduces harmful emissions and operational complexity.

While sublimation remains effective for producing ultra-pure silicon, it demands significantly more energy and involves more complex infrastructure. In contrast, the NaOH-based method offers a balance of simplicity, environmental compliance, and industrial applicability.

Nevertheless, the corrosive environment generated during the process may cause degradation of equipment, increasing installation and maintenance costs. Additionally, the recycling or neutralization of large volumes of NaOH and secondary products remains a technological challenge.

Despite these drawbacks, the NaOH-based recovery technology stands out as a viable and scalable approach to transforming silicon-rich metallurgical waste into valuable industrial products. Future work should focus on scaling up this process for industrial implementation and evaluating long-term operational and economic performance.

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